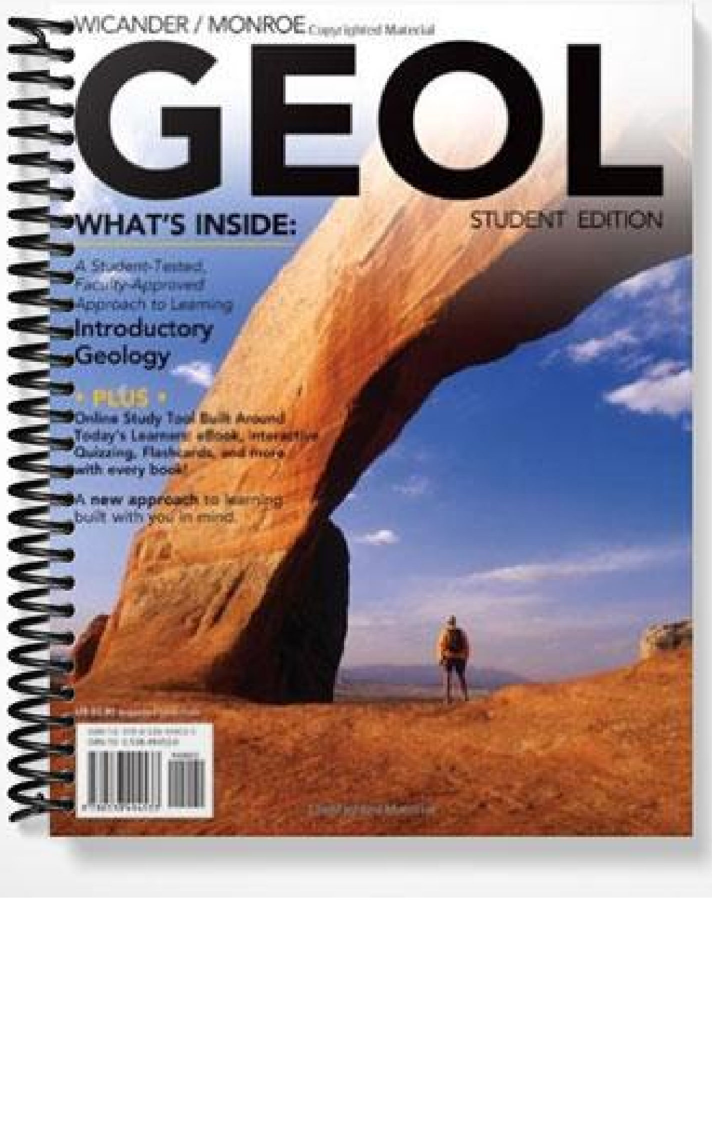
SOLUTIONS MANUAL



Chapter 2
Plate Tectonics: A Unifying Theory

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Learning Outcomes

After reading this unit, the students should be able to do the following:
LO1 Review early ideas about continental drift
LO2 Explain the evidence for continental drift
LO3 Describe Earth's magnetic field
LO4 Explain paleomagnetism and polar wandering
LO5 Explain magnetic reversals and seafloor spreading
LO6 Explain plate tectonic theory
LO7 Identify the three types of plate boundaries
LO8 Describe hot spots and mantle plumes
LO9 Explain plate movement and motion
LO10 Explain the driving mechanism of plate tectonics

LO11 Recognize the role of plate tectonics in the distribution of natural resources
LO12 Recognize the role of plate tectonics in the distribution of life

Chapter Summary

- The concept of continental movement is not new. The earliest maps showing the similarity between the east coast of South America and the west coast of Africa provided the first evidence that continents may once have been united and subsequently separated from each other.

- Alfred Wegener is generally credited with developing the hypothesis of continental drift. He provided abundant geologic, paleontologic, and climatologic evidence to show that the continents were once united into one supercontinent that he named Pangaea. The initial reaction of scientists to his ideas was mixed at best.

- The evidence for continental drift includes the fit of the continents, the similarity of rock sequences and mountain ranges across oceans, the remains of glaciers in locations that are too warm for glaciers today, and the presence of fossils of the same species on widely separated continents.

- The hypothesis of continental drift was revised during the 1950s when paleomagnetic studies of rocks indicated presence of multiple magnetic north poles instead of just one as there is today. This paradox was resolved by constructing a map in which the continents could be moved into different positions such that the magnetic data would then be consistent with a single magnetic north pole.

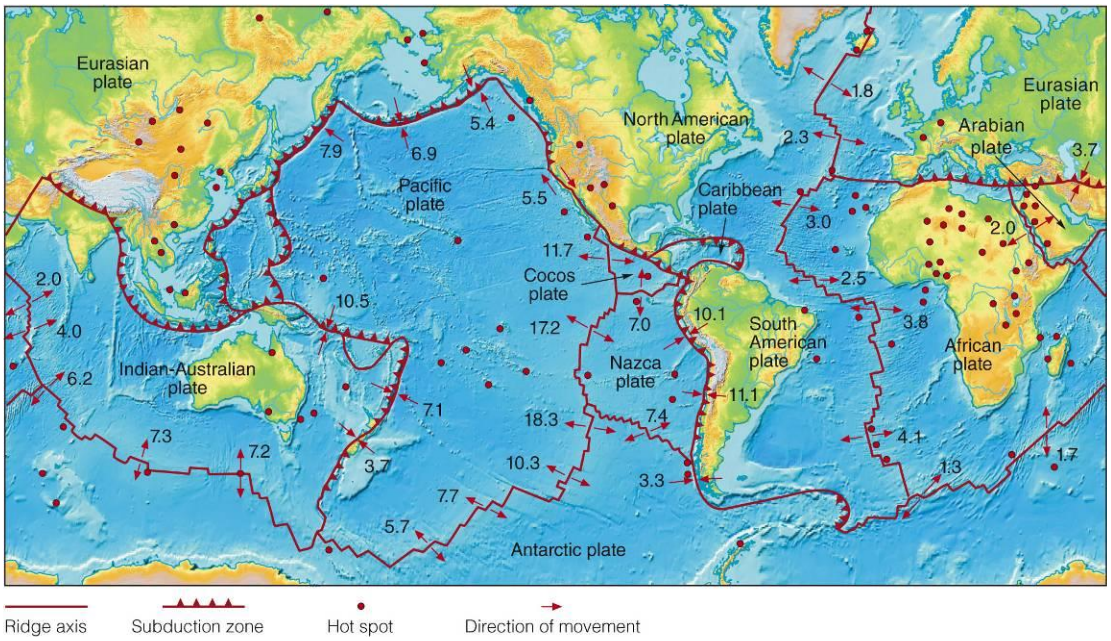
- Seafloor spreading was confirmed by the discovery of magnetic anomalies—reversals of magnetic polarity—in the ocean crust that were both parallel to and symmetric around the ocean ridges. The pattern of oceanic magnetic anomalies matched the pattern of magnetic reversals already known from continental lava flows.

- Plate tectonic theory became widely accepted by the 1970s because the evidence overwhelmingly supports it and because it provides geologists with a powerful theory for explaining such phenomena as volcanism, earthquake activity, mountain building, global climate change, the distribution of the world's biota, and the distribution of mineral resources.

- There are three types of plate boundaries: divergent boundaries, where two plates move away from each other; convergent boundaries, where two plates collide; and transform boundaries, where two plates slide past each other.

- Ancient divergent plate boundaries can be recognized by their associated rock assemblages and geologic structures. For divergent boundaries, these may include pillow lavas, rift valleys with thick sedimentary sequences, and numerous dikes and sills.

- The average rate of movement and relative motion of the plates can be calculated in several ways. The results of these different methods all agree and indicate that the plates move at different average velocities.



- The absolute motion of plates can be determined by the movement of plates over mantle plumes. A mantle plume is an apparently stationary column of magma that rises to the surface where it becomes a hot spot and forms a volcano.

- Thermal convection cells within the mantle move the plates. Hot magma rises and forms new crust; cold crust is subducted back into the mantle at oceanic trenches. Convection cells may be in just the asthenosphere or in the whole mantle.

- The supercontinent cycle indicates that all or most of Earth's landmasses form, break up, and form again in a cycle spanning approximately 500 million years.

- A close relationship exists between the formation of some mineral deposits and petroleum, and plate boundaries. Furthermore, the formation and distribution of some natural resources are related to plate movement.

- The relationship between plate tectonic processes and the evolution of life is complex. The distribution of plants and animals is not random, but is controlled mostly by climate and geographic barriers, which are controlled to a great extent by the movement of plates.

Lecture Suggestions

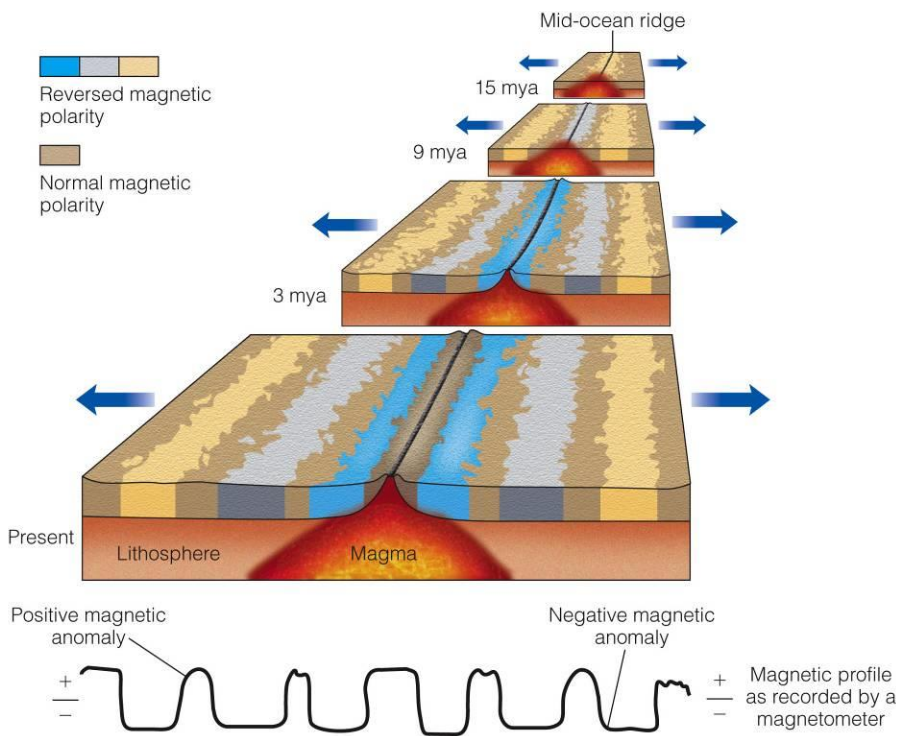
1. Use animations to teach plate tectonics. Technology aids in the understanding of plate motions with these fantastic animations from the University of California, Santa Barbara. Global Tectonics topics include Mesozoic Subduction, Pangaea, Himalayan Collision, Seafloor Spreading, South Atlantic Spreading, and Seafloor Spreading and Magnetic Reversals. Regional Plate Tectonics and Geologic Histories topics include Pacific Hemisphere Plate, 80 Ma to Present; N.E. Pacific and W. North American Plate History, 38 Ma to Present; and Plate Tectonic History of Southern California, 20 Ma to Present: http://emvc.geol.ucsb.edu/downloads.php#IceAge. More plate tectonics animations are found at the United States Geological Survey website: http://www.nature.nps.gov/Geology/usgsnps/animate/pltecan.html and at this University of California Berkeley site http://www.ucmp.berkeley.edu/geology/anim1.html

2. Relative rates of motion between tectonic plates are a difficult concept for many beginning geology students. The following is an illustration in which members of the class are designated as specific plates and plate margins that move with a set of tape measures.
   Setting: The western margin of North America 40 Ma, involving the Pacific, Farallon, and North American plates, a spreading ridge, and a subduction zone. Five students are designated as follows:
   Student 1 = Pacific plate.
   Student 2 = West side of spreading ridge; reels out Pacific plate with tape measure.
   Student 3 = East side of spreading ridge; reels out Farallon plate with tape measure.
   Student 4 = Farallon plate.
   Student 5 = North American plate and subduction zone; reels in Farallon plate.
   Given: Rate of Pacific plate with respect to North America plate = zero (therefore, students 1 and 5 are stationary in the illustration). Both students 2 and 3 reel out tape at a rate of 1 m/10 My (1m = 500km).
   Set-up: Two roll-up tape measures are used with a piece of bright electrical tape attached at each 1 in. interval.
   Student 1 stands on one side of the room.
   Students 2, 3, and 4 start approximately 3 meters from student 1.
   Student 5 stands across the room, approximately 8 meters from student 1.
   Students 2 and 3 move together throughout the demonstration and reel out tape at the same rate.
   Student 5 pulls in tape reeled out by student 3.
   Student 4 travels along with the tape reeled out by student 3.
   The following **table** is drawn on the blackboard:
   RATES OF MOTION
   Plate A relative to Plate B rate in km/My
   Pacific plate to North America plate. Given as zero.
   North America plate to ridge (50).
   Pacific plate to ridge (50).
   Farallon plate to ridge (50).
   Pacific plate to Farallon plate (100).
   Farallon plate to North America plate (100).
   The illustration is set up and run for each set of plates in the table. The difference in rates between each pair of students is easily ascertained.

3. Why was the concept of seafloor spreading necessary for continental drift to be accepted? How could scientists ignore the overwhelming evidence that the continents could move over the face of the Earth?

4. Demonstrate the relationship between hot spots and surface volcanic chains with a piece of paper and a lighted match. As you move the paper over the match, a burn trace is left with the oldest burn at the farthest distance from the match. Be careful!

5. For a better understanding of seafloor spreading, have the students try this demonstration.
   - Have 20 to 30 student volunteers gather in the central aisle of the classroom. They are referred to as the magma in the chamber underlying the central ridge axis. Have the students shuffle slowly to the front of the class in pairs, and upon reaching the front of the room, have each pair separate, one going left and the other to the right. When they reach the front of the room, have the students hold their arms up if the instructor's arms are up, or leave them down if the instructor's arms are down.
   - In this way, the plates grow at the front of the room, as the students diverge from each other at the ridge axis and are subsequently replaced by other students emerging from the magma chamber.
   - Students with hands up are normal polarity rocks and hands down are reverse polarity rocks. The bilateral symmetry of the paleomagnetic pattern and progression of rock age from oldest (first to come out) to youngest (last to come out) should now be obvious to most students. Having the students take a small step backwards for each minute that they are part of the new crust will generate the subsidence that older crust undergoes. By varying the rate at which the students walk and separate, various paleomagnetic reversal pattern widths and ridge topographies (East Pacific Rise vs. Mid Atlantic Ridge) can be generated.



6. Note that the direction of plate movement at any given point along a spreading ridge or subduction zone must be perpendicular to that spreading ridge or subduction zone.

7. Stress the differences between continental and oceanic crust and between the lithosphere and the asthenosphere. Note especially the rigid behavior, lower density, and brittle, highly fractured nature of the continental crust.

8. A pot of boiling soup with its surface crust is a useful analogy for describing the process of convection cell motion.

Enrichment Topics

Topic 1. Pre- and Post-Pangaea Supercontinents. Pangaea, which started splitting up about 200 million years ago, was not the first supercontinent. Rodinia was together about 1 billion years ago, and there is evidence for a supercontinent as many as 3 billion years ago. How does the geologic history of Rodinia parallel that of Pangaea? What is the geologic evidence that the continent was once together and then broke up? The Burke Museum of Natural History and Culture, University of Washington, 2006: http://www.washington.edu/burkemuseum/geo_history_wa/Dance%20of%20the%20Giant%20Continents.htm

Topic 2. Crazy Ideas in Science. Alfred Wegener's continental drift idea turned out to be true. Some of the other "Crazy Theories that Turned Out to Be True" involve ice ages and the asteroid impact theory for the dinosaur extinction. *Christian Science Monitor*, November 9, 2004: http://www.csmonitor.com/2004/1109/p18s02-hfks.html

Topic 3. Source of Hot Spot Mantle Plumes. Geophysicists and geochemists have argued about the depth of the sources of mantle plumes. Recent experiments from seismic tomography show that plumes come from a variety of depths. Well-resolved plumes that come from the deepest mantle include Ascension, Azores, Canary, Easter, Samoa, and Tahiti. Hawaii, which is long-lived and voluminous, is less well-resolved and may come from deep. Evidence for several plumes is only found in the upper mantle, including Bowie, Eastern Australia, Eifel, Etna, Iceland, Cocos-Keeling, Galápagos, and Juan de Fuca/Cobb. Montelli et al., *Science*, 303: 338–343, January 16, 2004.

Topic 4. Do Mantle Plumes Really Exist? This question has been around for a while, and a good non-technical summary of the controversy is discussed on about.com, which includes links to other articles: http://geology.about.com/od/platetectonics/a/nohotspots.htm

Topic 5. Is Plate Tectonics Inevitable? Plate tectonics may be a necessary condition for life, so the existence of plate tectonics on other Earth-like planets is important for determining whether life may exist on those planets. Using the article "Inevitability of Plate Tectonics on Super-Earths" in *The Astrophysical Journal*, have the students discuss why plate tectonics may be necessary for life to exist on a planet and how likely these large planets are to have plate tectonics. How can astronomers test whether a large planet is tectonically active and is home to living things? http://www.iop.org/EJ/abstract/1538-4357/670/1/L45/

Common Misconceptions

Misconception: Earth is molten, except for its crust.
Fact: Only small pockets of magma are molten; the rest of the Earth is solid. Some, like the asthenosphere, are solid but can flow plastically.

Misconception: The crust moves on top of the mantle.
Fact: This is a simplified picture of plate tectonics. In reality, the lithosphere, which includes both the crust and the solid uppermost mantle, moves about on the underlying asthenosphere, the part of the mantle exhibiting plastic behavior.

Misconception: Ridges are fixed in space.
Fact: Spreading ridges can move laterally across the upper mantle.

Consider This

1. Why is plate tectonics given the status of theory while continental drift attained only the status of hypothesis?

2. Since plate movements have been directly measured, is plate tectonics a theory or a fact? Why?

3. Compare and contrast continental drift and the plate tectonic theory. What does plate tectonics have that continental drift does not?

4. What is the origin of the term "transform" in transform fault?

5. Why are transform faults associated with spreading ridges, at approximately right angles to the ridge? Why don't transform faults intersect subduction zones as well?

6. Why can spreading ridges never be directly connected to subduction zones, but instead the two must be linked by a transform fault?

Key Terms

continental–continental plate boundary
continental drift
convergent plate boundary
Curie point
divergent plate boundary
Glossopteris flora
hot spot
magnetic anomaly
magnetic field
magnetic reversal
magnetism
oceanic–continental plate boundary
oceanic–oceanic plate boundary
paleomagnetism
Pangaea
plate tectonic theory
seafloor spreading
thermal convection cell
transform fault
transform plate boundary

Internet Sites, Videos, Software, and Demonstration Aids

Internet Sites

1. Historical Perspective: http://pubs.usgs.gov/gip/dynamic/historical.html
   An historical explanation of the development of plate tectonics theory from the United States Geological Survey.

2. The PLATES Project: http://www.ig.utexas.edu/research/projects/plates/index.htm
   From the Institute for Geophysics at the University of Texas, the PLATES project provides a resource for plate tectonics media, publications, and teaching resources.

3. This Dynamic Earth: http://www.mnh.si.edu/earth/
   Four topics are covered in this website by the Smithsonian National Museum of Natural History, including Plate Tectonics and Volcanoes.

4. Mantle plumes.org: http://www.mantleplumes.org/
   A blog discussing the origin of "hotspot" volcanism frequented by some of the top names in the field.

5. Northern California Earthquake Data Center (NCEDC): http://quake.geo.berkeley.edu/
   Information on earthquakes in northern California, including recent epicenters and news.

6. GPS Time Series: http://sideshow.jpl.nasa.gov/mbh/series.html
   Global Positioning System (GPS) receivers are used to determine precise geodetic position measurements each day to chronicle plate movements.

Videos

1. *Global Tectonics: Competing Theories.* Insight Media, DVD (2006, 22 min.)
   The history of plate tectonic theory and how the plates got to be in their current positions.

2. *Plate Tectonics.* Insight Media, DVD (2004, 25 min.)
   The development of plate tectonics theory as an example of the process of scientific inquiry.

3. *World in Motion: Plate Tectonics.* Insight Media, DVD (2003, 27 min.)
   The supporting evidence for plate tectonics.

4. *Making the Pieces Fit: Continental Drift Theory.* Insight Media, DVD (2003, 27 min.)
   The study of deep earthquakes and their impact on plate tectonics theory.

5. *Earth Revealed.* Annenberg Media: http://www.learner.org/resources/series78.html
   (1992, 30 min., free video):
   - #5: The Birth of a Theory. The development of continental drift, seafloor spreading, and plate tectonics theory.
   - #6: Plate Dynamics. The movement and interaction of tectonic plates and the geological phenomena they account for.

6. *Planet Earth.* Annenberg Media: http://www.learner.org/resources/series49.html (1986, 1 hour, free video)
    - #1: The Living Machine: The Theory of Plate Tectonics. Plate tectonics revealed at geological sites, such as Kilauea volcano and the Atlantic seafloor.
    - #5: Gifts from the Earth. Earth's Natural Resources. Plate tectonics and how it has revolutionized the way geologists search for natural resources.

Software

1. *Plate Tectonics and How the Earth Works.* Tasa Graphic Arts, Inc.
   The origin and evolution of the continents and the early history of the Earth.

2. *The Theory of Plate Tectonics.* Tasa Graphic Arts, Inc.
   The changes of Earth's lithospheric plates through time.

Slides

1. Tasa Photo CD-ROM: Tectonics and Mountain Building. Tasa Graphic Arts, Inc.
   Earth science photographs to illustrate lectures or Power Point Presentations.

Demonstration Aids

1. *A Continental Drift Flip Book.* PALEOMAP Project, University of Texas.
2. *The Puzzle of the Plates.* American Geophysical Union, 18 movable pieces, 4 frame pieces, 16-page booklet.
3. *Continental Drift and Plate Tectonics.* Educational Images, Ltd., Slide set.